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RANDOMIZATION and FACTORIAL EXPERIMENTS

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There are numerous situations in science and engineering where one is confronted with the problem of studying and controlling systems affected simultaneously by many factors. The formulation of suitable policies in these areas often requires the understanding of such complex systems. Moreover, the effective carrying out of policy invariably involves the stability of the system. That is, decisions based on an understanding of the system require conviction that no significant changes have occurred while such decisions are being carried out.

In order to study the main effects of all the factors which comprise a system and all the possible joint effects (interactions) of the factors, one must test the system under all possible combinations of different levels of these factors. The number of such combinations increases very rapidly with the number and levels of the factors. If there are 15 factors each at only two levels, the number of combinations is equal to $2^{15} = 32768$. For 20 factors it is equal to $2^{20} = 1{,}048{,}576$. In general for m factors each at p levels we have p^m combinations.

Experimental designs suited for studying systems of the type described above are the Factorial Designs. The need to reduce the number of experiments has led to the development of the Fractional Factorial Designs. In these designs only a fraction of the treatment combinations are tested. However, the designs have the shortcoming that effects of importance may be confounded with other effects, leading to biased estimates. In short, the analysis in the Fractional Factorial Designs requires assumptions concerning certain effects. These usually involve the assumption that interactions of a certain order are negligible. More-

over, these designs are often used for exploratory purposes (or for keeping check on the stability of the system) where one wishes to consider many possible factors and where interactions, even of high order, cannot always be assumed to be negligible.

Thus, there is evidently a need for the development of procedures which allow inferences to be made without the restrictive assumptions, and which keep the number of experiments to a minimum and utilize any information about parameters in an optimal way. To satisfy this need the Applied Mathematics Division of AFOSR has been supporting Dr. S. Ehrenfeld of New York University in a research program entitled "Randomization and Factorial Experiments."

The aims of the research are to investigate the different forms in which information may be available, to study the relationship between information and the role and efficiency of randomization procedures, and to determine the optimal use of the available information and the implications for randomization. Professor Ehrenfeld has studied general factorial experiments in which a subset of preassigned factors is of particular interest and where the remaining factors are treated as nuisance parameters about which varying degrees of information are available. So far, as indicated by a recent paper, an analysis of variance scheme for assessing the importance of the preassigned parameter and the nuisance parameters has been obtained. Optimal strategies for inference about parameters, with various randomization procedures, have also been obtained. In addition, the question of whether or not to randomize has been resolved for several different states of information, with respect to nuisance parameters. The information gained so far is useful in the design of industrial experiments.

A CLOSE LOOK AT AN ARC CATHODE

CHARLES A. DAVIES, Thermomechanics Research Laboratory, ARL

Plasma arcs, from the standpoint of current-carrying characteristics, are generally considered to contain three distinct regions. These are the anode, cathode, and arc-column regions. Obviously, there must be transition zones between these regions as well as progressive changes within the regions. However, the complexity of arc processes and the difficulty of charting the paths of electrons, ions and atoms have led to many analytical models which are based on simplified assumptions that ignore the subtle changes throughout the length of arcs.

Dr. T. H. Lee of the General Electric Company, Philadelphia, has been investigating cathode-region phenomena as a part of an overall study of plasma arcs by the Thermomechanics Research Laboratory. He has attempted to subdivide the cathode zone into smaller regions and to find matching solutions for those regions. Through profound reasoning, Dr. Lee has formulated a logical analysis of the processes which must occur near the cathode of a particular arc. The arc selected was a 200-ampere carbon arc in argon at atmospheric pressure. Initial calculations, which will be refined as the research progresses, indicate the feasibility of his analysis, and also point out the extreme difficulty of formulating a rigorous solution for the cathode region and matching solutions for the arc-column and anode regions.

The cathode region is so small that it defies experimental diagnosis. For the arc selected, the length of the cathode region of interest is only 10^{-2} cm, and this is divided into four subregions. Figure 1, which is only roughly to scale for an arc of the type shown in Figure 2, describes this region. In his report, Dr. Lee showed only four lines, with the region descriptions on the left. This reviewer, in an attempt to present a better picture of the cathode phenomena, has taken the liberty of adding dimensions and other embellishments based on information contained in Dr. Lee's report. Of course, the process is far too complex for pictorial representation. It is hoped, however, that

Figure 1, plus the following explanation, will help clarify the process for the layman by showing some of the reactions which take place in each region.

Region I, a very narrow zone next to the cathode, is called the ion free-fall zone. At the cathode surface, the arc is contracted to an area of 4 mm^2, raising the current density to 5000 amps/cm^2 and the temperature to 4000°K. Every second each sq. cm. of the cathode is bombarded by 3 x 10^{21} ions which are inertia-controlled and fall freely through Region I. Electrons are emitted from the cathode and fall freely through Regions I and II. By definition, a mean free path allows 60 to 70 per cent of particles to experience collisions before the path is completed. Applying this correction and a directional correction, the ion and electron free-fall distances are determined and are used to establish the I-II and II-III boundaries. In Region I, we also find a small number of back-diffusing electrons which move in a direction opposite to the emitted electrons and partially neutralize the ions. Region I has a positive space charge. Figure 3 shows that the cathode potential fall occurs primarily in Region I , and that the electron temperature is much higher than the gas temperature there.

TYPICAL 200 AMP CYLINDRICAL ARC

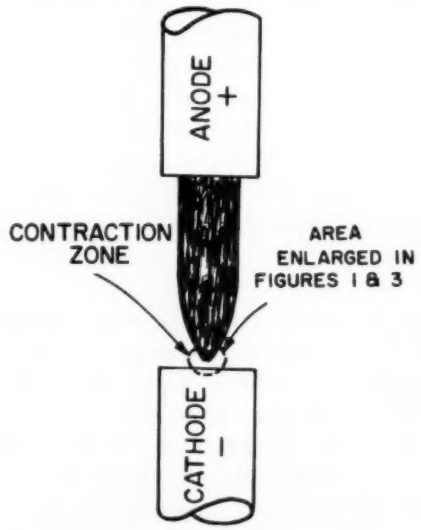


Fig. 2

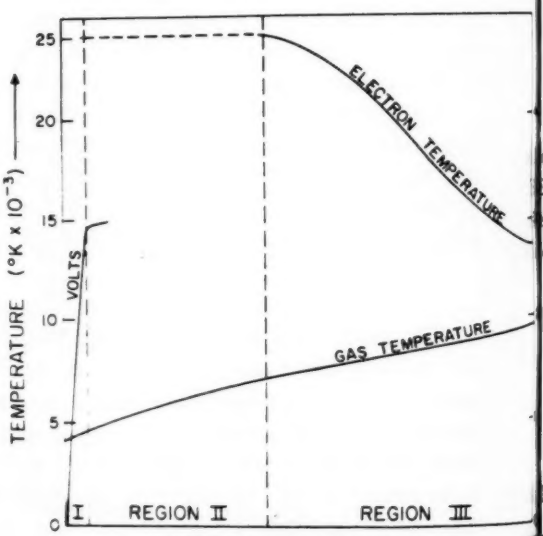
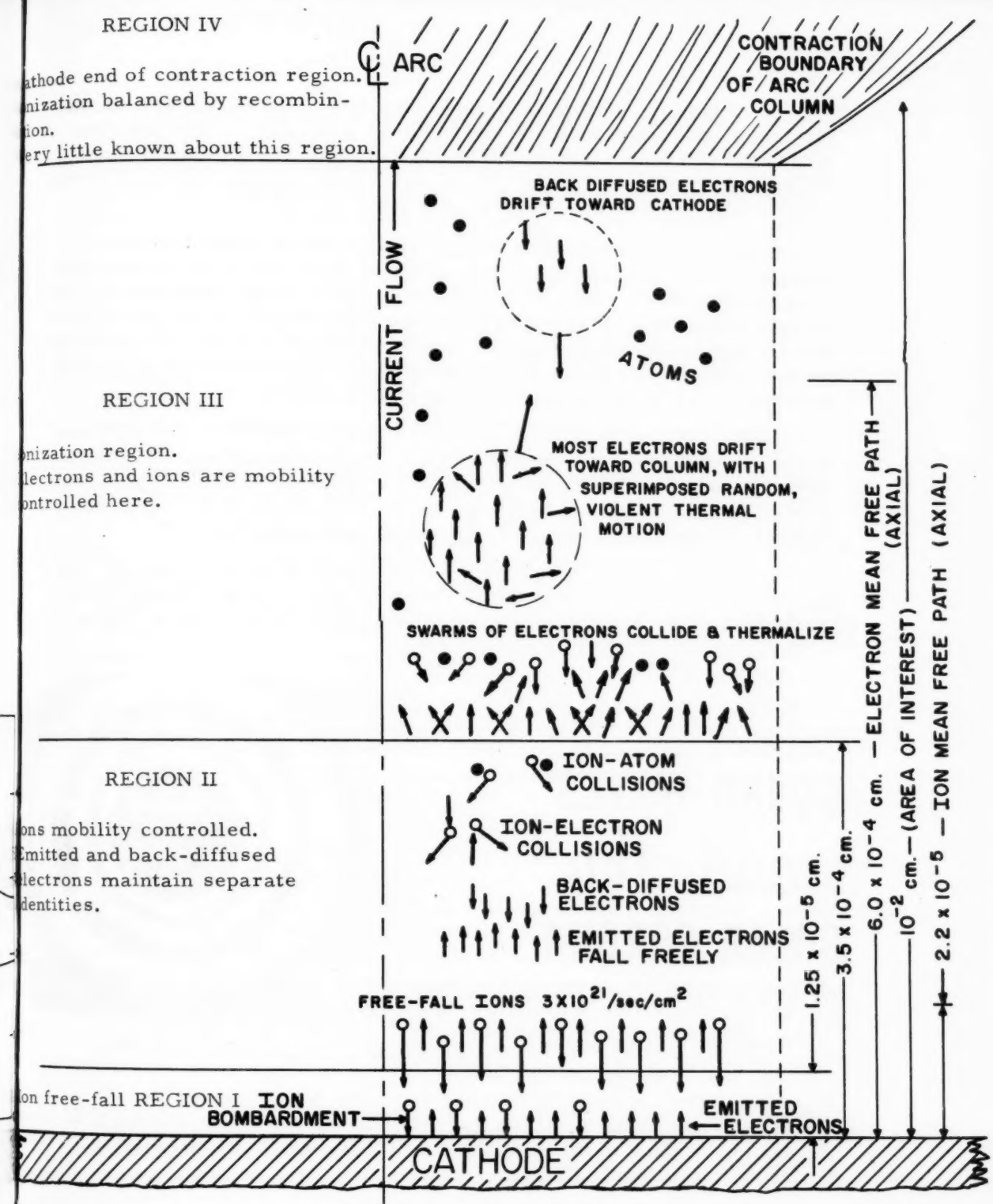


Fig. 3



Current density 5000 Amps/cm^2. Spot area 4 mm^2. Surface Temperature 4000°K.

Fig. 1

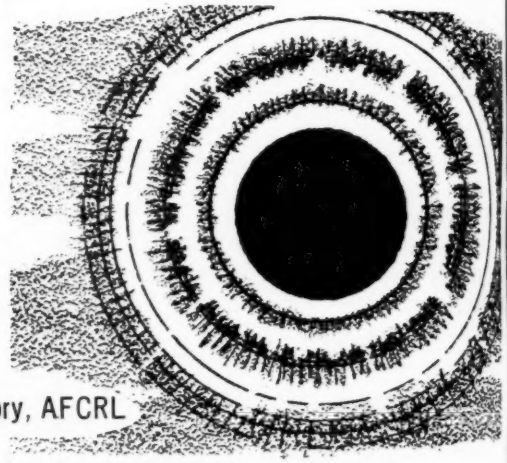
In Region II, ions drift toward the cathode and collide with atoms, electrons, and other ions and are mobility-controlled. Emitted electrons still fall freely and maintain separate identities from the back-diffused electrons. The electron temperature remains high (25,000°K) while the gas temperature rises from 4000° to 7000°K.

Region III is believed to be the location where most ionization occurs. At the II-III boundary, swarms of electrons collide with argon atoms and scatter. This causes thermalization of the electrons and the heavier particles. The electron temperature drops and the gas temperature rises as shown in Figure 3. Both electrons and ions are mobility-controlled in this region. It appears that the current-carrying function is transferred from ions to electrons in this region.

Region IV is the cathode end of the contraction zone of the plasma where ionization is assumed to be balanced by recombination. Future investigations will be concentrated on this zone which has not yet been studied in detail. As the building blocks fall into place for the other regions, analysis of Region IV may be simplified further.

Dr. Lee's initial results will be published as an ARL report, and his research will continue. He presented a paper on this research at the Sixth International Symposium on Ionization Phenomena in Gases held this month at Orsay (Paris), France.

SOUND WAVES *and the* SOLAR CORONA



DR. JOHN W. EVANS, Space Physics Laboratory, AFCRL

For the last 20 years solar physicists have realized that the corona, that beautiful, quiet-looking, filmy envelope seen around the sun at eclipses, is actually one of the hottest objects in sight. Its temperature is about a million degrees Kelvin, some 170 times that of the visible surface of the sun (about 6,000°K, which is still a lot hotter than a welder's flame).

In colder outer space, the corona would cool off very quickly if it were not continually heated. The source of this coronal heating has become one of the most puzzling of solar problems. The explanation will surely tell us a great deal more about the solar atmosphere than just the mechanism for getting energy into the corona.

The most promising explanations of coronal heating are based on the theory of sound waves or acoustic noise proposed independently by M. Schwarzschild and L. Biermann in 1948. The sun that we see through a telescope is grainy in appearance, due to neighboring hot and cool areas at the tops of upward-and downward-moving convective columns. The visible surface is an irregular heaving, surging, boiling layer. This motion induces sound waves which carry mechanical energy, propagating upward into the chromosphere and finally into the corona. Here they run into sound-absorbing conditions and are damped out, giving up their energy as heat which maintains the high, observed temperatures of the corona.

This is a quite adequate theory, but until recently there was no way to test it. Several instruments and techniques have now come along which are being used by scientists at the AFCRL Sacramento Peak Solar Observatory to study the motions in the solar atmosphere. These motions generate the sound waves which, in turn, give the corona its ultrahigh temperatures.

Essentially, the Sacramento Peak Solar Observatory scientists wish to measure the vertical velocities of the surging solar granules which we see in our telescopes. When we speak of these granules, we are referring to a solar area measuring something like 2000 to 3000 kms across. Measurements of their turbulent velocities is made by Doppler means.

Improved diffraction gratings now give a 5-to-10-fold increase in the detail of spectrograms over the detail of spectrograms made a few years ago. While these new gratings provide more precise data, there is still the matter of analysis. Within the last year or so, the analysis problem has been greatly simplified. The spectrogram is made by projecting a sharp image of the sun on a spectrogram slit. Where this slit crosses the images of upward and downward moving areas on the sun, the lines of the spectrum at corresponding points are displaced toward the violet or red.

The information required of a particular line is its Doppler displacement. We can measure these displacements with a microscope, but this is tedious and not very accurate. A microphotometer has recently been developed which traces along the line and records

Doppler displacements directly on a chart recorder. The first such Doppler recorder was developed by the Meudon Observatory. A second one at Sacramento Peak has an additional amenity. While recording the line shifts on a chart, it also punches them numerically on IBM cards for computer analysis. With this equipment at Sacramento Peak, we are approaching that scientist's paradise where data reduction can keep up with the rate of observation.

With the new instrumentation and techniques now available, scientists at the AFCRL Sacramento Peak Solar Observatory have found that the velocities of motions of the turbulent solar gases correspond to the velocities needed for generating the sound waves predicted by theory. In a detailed article prepared for the June issue of Sky and Telescope,

the Director of the Sacramento Peak Observatory, Dr. John W. Evans, offers this explanation for the high corona temperatures:

The visible surface of the sun is a resonant layer, and any strong disturbance results in vertical oscillations near the resonant frequency. As the resulting longitudinal waves carry the energy upward, they encounter lower and lower densities in the solar gas. This results in a corresponding increase in the amplitude of the motion with height.

As the waves go into the chromosphere, the amplitudes become so great, due to decreasing density, that the peak oscillatory velocities become a large fraction of the velocity of sound, and the waves begin to fall over themselves in more or less chaotic shock waves. In the upper chromosphere and corona these shocks run into severe "friction" and give up their kinetic energy in the form of heat, raising the corona to the observed temperature of about a million degrees.

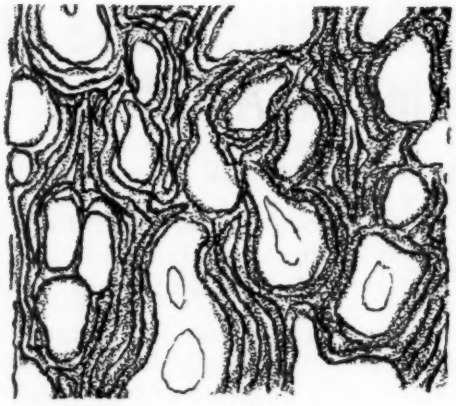
THEORETICAL MODEL FOR RING CLOSURE IN INORGANIC POLYMERIZATION

DR. W. L. LEHN, Air Force Materials Laboratory, ASD

A theoretical model for ring closure in inorganic polymerization has been derived at Michigan State University under contract to the Polymer Branch, Nonmetallic Materials Division, AF Materials Laboratory.

Most of the mathematical models developed to describe the mean square end-to-end dimensions of polymers with restricted but discrete rotational states are valid only for high-molecular-weight polymer chains. Such equations are adequate to describe the equilibrium dimensions of many hydrocarbon chains such as polyethylene, polypropylene, and polyisobutylene because only relatively high-molecular-weight chains and no small cyclic molecules are present. It is quite a different matter for inorganic polymers since cyclic species are formed to an appreciable extent in many inorganic polymerizations. The model used in this work deseribes the polydimethylsiloxane chain, a prime example for cyclic formation in an inorganic polymer system, since cyclic molecules containing from six to eighteen atoms in their skeletal structure can make up twenty per cent by weight or more of the equilibrated system. Existing theories fail to explain this phenomenon because of approximations which allow the equations to be valid only for chains containing at least 100 links.

The first step of this program has been successfully completed, since general equations have been developed for the siloxane and similar chains which are valid for any number of links in the chain. The equations have been programmed in FORTRAN for the 160A Control Data Computer, and two independent tests of the validity of the equations have proven successful. These equations will be applied to a study of the polydimethylsiloxane equilibrium with the purpose of predicting and explaining the experimentally observed linear chain-cyclic distribution as quantitatively as possible. It is hoped that, once the siloxane system has been explained, the methodology used will prove to be of general application to the field of inorganic polymers. This may lend additional insight leading to new polymers or polymerization methods enabling scientists to prepare new, thermally stable inorganic polymers to meet Air Force high-temperature materials requirements.



FUNDAMENTAL MECHANICAL PROPERTY BEHAVIOR OF ELASTOMERS

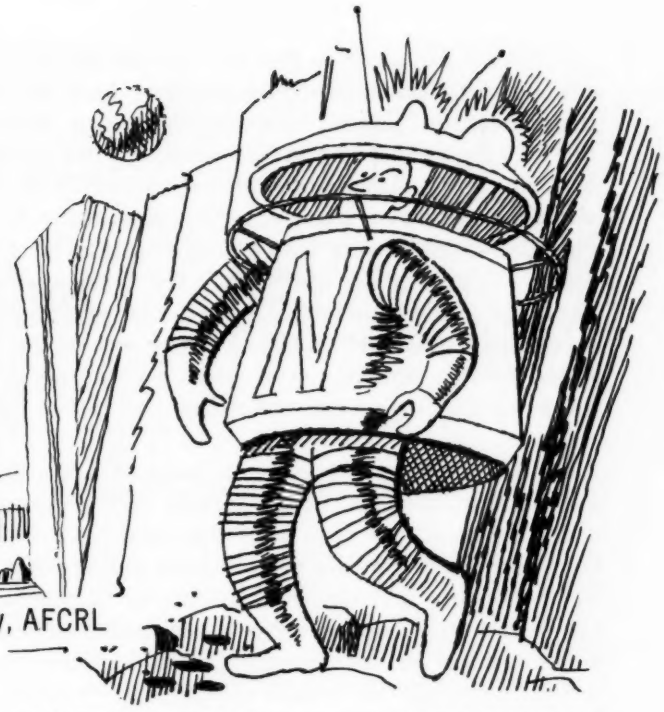
RAYMOND G. SPAIN,
Air Force Materials Laboratory, ASD

Considerable progress has been made toward the development of a comprehensive theory regarding the tensile strength and elongation properties of amorphous elastomers through the efforts of Dr. F. Bueche, University of Dayton, and Lt. J. C. Halpin, Elastomers and Coatings Branch, Nonmetallic Materials Division, Air Force Materials Laboratory. Previously, Dr. Thor L. Smith, Stanford Research Institute, working under an Elastomers and Coatings Branch contract, had shown that the tensile strength and ultimate elongation properties of a given amorphous elastomer can be described by a characteristic failure curve. Recent in-house research shows that this failure curve can be predicted from a knowledge of the creep curve of the elastomers. This new theory relates the ultimate properties to the viscoelastic properties of the elastomer and is based on the idea of a propagating crack, the rate of propagation being limited by viscoelastic mechanisms. From the observation that the failure envelope follows as a natural consequence of the viscoelastic behavior of the elastomer, we can deduce from the principle of corresponding viscoelastic states that the principal effect of the repeating chemical unit in the polymer chain of the elastomer affects rupture properties only insofar as the latter affects the glass temperature. As a rough approximation we can state that, at equal increments from the glass temperature, for a comparable degree of vulcanization, we will have equivalent rupture properties.

The implication of this work regarding efforts to attain elastomers possessing adequate strength at high temperatures include the following: (a) innate chemical and thermal stability of the polymer is mandatory; and (b) additional physicochemical processes (such as reinforcement) must be developed to attenuate the loss of strength with temperature. Both approaches are being followed in the Nonmetallic Materials Division.

ENVIRONMENT SENSING..... a Novel Approach

WALTON B. BISHOP,
Solid State Sciences Laboratory, AFCRL



If we place an unmanned tractor on the moon or Mars and send this tractor off on an exploratory cross-country journey, we want to make sure that it doesn't fall into a crevasse and is never heard from again. To avoid this, the tractor must be equipped with some kind of environmental sensing system. The sensor that readily comes to mind is a sonic sensor of the type used by bats to avoid obstacles. But suppose we wish to give our vehicle a passive optical sensor, one having the properties of sight-that is, a sensor that would detect environmental obstacles solely on the basis of reflected light from these obstacles. What would the system be like, and what are some of the considerations that must be observed in its design?

It turns out that such a sensor might not prove to be unduly complex. Further, the same kind of sensor developed for an unmanned planetary tractor might very well be adapted for use by the blind. Walton Bishop, in a recently issued AFCRL report, "Environment Sensing--A New Approach to the Design of an Electronic Aid for the Blind," (AFCRL-63-64), discusses a generalized system. The report describes possible types of optical sensors, the geometrical considerations permitting the sensor system to orient itself with respect to environmental obstacles, and reviews the kinds of environmental obstacles with which the system must cope.

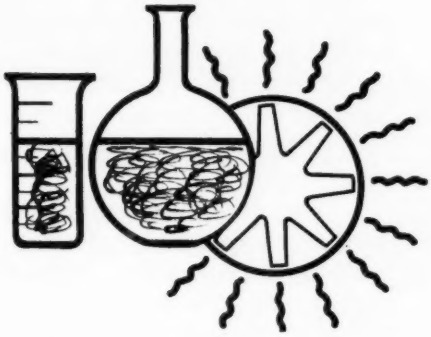
With respect to the use of the sensor by a blind person, Bishop discusses a possible transducer--that is, a technique for converting the electrical signal from the sensing device into a form that can be readily detected and understood by the blind person. Because the blind person already must rely heavily on his hearing, the transducer should not convert the electrical signals to acoustical signals. Bishop proposes that these electrical signals be converted to vibrations that can be detected by the skin. He discusses a number of environmental hazards and situations likely to be encountered by the planetary tractor--or a blind person. Among these are pitfalls, finding bearings from three known points, step down and step up, low overhead objects, and the recognition of approaching and departing objects.

The entire system consists of a sensing device, a data processor, and a transducer. The sensing device described grows out of an effect noted in an AFCRL report published in 1947. It was accidentally discovered during some laboratory experiments that natural reflected light passing through two properly aligned pinholes onto a photomultiplier produced some very interesting effects. When the output of the photomultiplier was amplified and connected to a pair of earphones, it was possible to detect variations in the texture of objects in the field of view. Bishop proposes that the output information on the texture of objects be converted into a series of coded pulses to be sensed by the skin. The brain, over a period of time, should be able to correlate these pulses with the nature of the objects in the visual field.

This particular sensor would be highly directional. It would be used in conjunction with a wide-angle directional sensor for locating objects that cannot be found easily with the more directional sensor. The wide-angle sensor suggested by Bishop has the same general design as the directional sensor. The only difference stipulated is that the first of the two pinholes have a larger aperture (or that the distance between the two pinholes be shortened). It is possible, through simple adjustments, to quickly convert the highly directional sensor into a wide-angle sensor, thus achieving both wide-angle and highly-directional capability into a single sensor.

AFCRL does not plan to develop any experimental devices leading to an environmental sensing system. Bishop's work is primarily an exercise in problem-solving of the type that scientists, on their own initiative, often become engrossed in.

ORGANIC SEMICONDUCTORS AND CANCER



DR. ALTON F. ARMINGTON, Solid State Sciences Laboratory, AFCRL

Organic semiconductors have one big potential advantage over the more familiar nonorganic germanium or silicon semiconductors. They may be easier to make and thus may be less expensive. Another potential advantage is that they may operate much more effectively as photoconductors. For these and other reasons, many people are studying them.

The AFCRL organic-semiconductor program is carried out largely under contract. One of the contractors, New York University, is looking into the electrical properties of polynuclear aromatic hydrocarbons. Essentially, these compounds consist of linked benzene rings. When various atoms such as sulphur, nitrogen, or oxygen are placed in the proper position on these rings, the compound exhibits desirable electrical characteristics. The New York University group under Dr. Walter Brenner, in investigating these hydrocarbons, has uncovered a very interesting relationship. Those organic semiconductor materials having the most favorable semiconductor properties are also known to be cancer inducing. Those compounds that do not exhibit semiconductor properties, even though closely related, are not biologically active.

Feeding of certain of these semiconducting hydrocarbons to rats has produced both cancer and cell destruction. The question which Dr. Brenner and his group would like to answer is whether electrical properties of the materials can be directly correlated with cancer-causing effectiveness. He would also like to explain the mechanism by which the material induces these pathological conditions.

It has been theorized that the molecule of the organic semiconductor compound is bound to the tissue protein by formation of a charge-transfer complex between the tissue protein and the compound. A mechanism involving electron transfer from the protein to the hydrocarbon has been postulated by others, and the idea of electron transfer from DNA to the hydrocarbon has also been advanced. Ionizing radiation could produce similar effects.

Dr. Brenner, under AFCRL contract, is now undertaking preliminary experimental studies as to the existence of such charge-transfer complexes. Initial experiments are being carried out with simple model compounds to determine the possibility of their charge-transfer formation with polynuclear aromatic hydrocarbons. Further investigations of these materials may not only throw important new light on the relationship between electronic structure and cancer induction, but may also show something of the mechanism of cancer activity by chemical and radiation means.

AFCRL *Notes*

La VERNE E. WOODS, AFCRL

Two AFCRL rockets were launched this past June. The first, an Aerobee rocket designed to measure the intensities and the spectral distribution of soft X-radiation from the lunar surface, was sent up during the week of 10 June from the White Sands Missile Range. (In similar rocket probes conducted within the past year by AFCRL, unexpected sources of X-radiation from deep within our galaxy were discovered.) In addition to measuring lunar X-radiation, the instrument package surveyed the sky for other possible sources of X-radiation. The vehicle, with a 216-pound pay load, reached an altitude of about 150 miles. Information was telemetered to the ground, and the system was recovered. Very good data were obtained. (SPACE PHYSICS LABORATORY)

The second launching was made during the week of 24 June. An Aerobee rocket was shot up from the Eglin Gulf Test Range to explore the possibilities of controlling ionospheric processes by the emission of radio energy at the electron gyrofrequency. Pay load was about 300 pounds, and was carried to an altitude of about 100 miles. Information was telemetered to the ground. (UPPER ATMOSPHERE PHYSICS LABORATORY)

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